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Naval Medical Research and Development Command
Research Work Unit M0100.001-1014

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SUMMARY PAGE

PROBLEM

To compare the performance of sonarmen under blue and white light of equal brightness and to ascertain their opinions of the two colors of ambient light.

FINDINGS

Of the nearly 200 sonarmen who compared blue and white light in the Sonar Operational Trainers, two-thirds preferred blue to white light for general ambient illumination. However, there was general agreement that white light was better for certain pieces of equipment, such as the AN/BQQ-3 and AN/BQR-21, as well as for the log-keepers and those men required to read publications. Moreover, detection and classification of targets was faster under white light than blue. In addition, four of the five sonar crews which evaluated the white lights at sea preferred the white light, including two crews that had preferred the blue in the SOT.

RECOMMENDATIONS

Neutral density filters which allow the same brightness as the blue filters, should be made available to those crews which want them. Also, future research should be done on SSN and Trident submarines to evaluate sonar performance on the AN/BQQ-5 and AN/BQQ-6 which have a different phosphor color than the equipment in the present investigation.

ADMINISTRATIVE INFORMATION

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ABSTRACT

Twenty sonar crews (mean = 9.7 men) undergoing refresher training in the Sonar Operational Trainers (SOT) for two to five 8-hour days evaluated the acceptability and effectiveness of blue and white ambient lighting. In addition, five crews evaluated the white lighting at sea. Of the nearly 200 men tested in the SOT, two-thirds preferred blue to white lighting, although there was general agreement that such pieces of equipment as the AN/BQQ-3 and AN/BQR-21 should be white lighted. Of the five crews tested at sea, four preferred white and only one preferred blue. Two of the crews that preferred white had originally preferred the blue lighting when tested in the SOT. Possible reasons for this change are discussed.

INTRODUCTION

Red lighting has been used in all submarine control areas, including the sonar shack, to promote dark adaptation for the men in the old fleet-type boats which regularly surfaced at night. When this need was eliminated, red lighting was retained primarily for the periscope operator and also in case of an unanticipated need to surface at night.

The continuing requirement for red lighting in submarines is controversial, however, and particularly difficult to justify in sonar shacks. When sonar information was only auditory, the type of lighting was unimportant, but today the information is displayed visually as well. In fact, in the newest systems the information from sonar sensors is almost entirely displayed upon cathode ray tubes (CRTs). If the use of a red light is to be continued, good reasons must be put forth, since it has always been unpopular. Indeed, dissatisfaction with traditional low-level red lighting in sonar control rooms has recently resulted in a switch to blue overhead lighting on a number of submarines.[1] This began when one crew, dissatisfied with the red lighting, decided to try the broadband blue lighting on their own initiative. They reported that the blue light led to a significant enhancement of sonar performance. This evaluation prompted the authorization of an official test of blue lighting.[2] The resulting favorable evaluation led to the directive[3] that sonar control rooms be blue-lighted. There was, however, no scientific evaluation of the blue lighting before it was installed and no attempt to ensure that the same light level was being maintained.

There appeared to be many possible reasons for the popularity of the blue light. The first is that, as many studies have shown, blue is typically the most preferred color by adults.[4-7]

A second possible reason was simply the satisfaction that accompanies a change that people have brought about for themselves.[8] The blue light was a novelty which had never been used in submarines, and it was initially installed at the request of the sonar crews themselves rather than being mandated by lighting experts and shipbuilders.

A third reason rests on the psychological phenomenon of group conformity. People often conform to the opinions of their group or their leaders, especially if they feel they have little to lose by so doing.[9] There is some evidence that this may be a reason, because not all the crews interviewed preferred the blue light, and, moreover, there was a surprising unanimity among the members of each crew, whether they preferred the blue or the red.[1]

A fourth reason is that long wavelengths (red light) produce some physiological discomfort and degradation. They require more accommodation to focus them on the retina, which could be uncomfortable for older men or far-

sighted men. And indeed, a study of the eye-movements of men monitoring a sonar display for two hours under different colors of ambient light gave some evidence of greater physiological fatigue under red light than under blue or white.[10] Other studies, have reported that red light has a deleterious effect on such measures as hand tremor and galvanic skin reflex.[11-14] Küller[15] showed that color had profound effects on EEG, pulse rate, and emotions. Halpern and Feinmesser[16] claim that blue light on the other hand elevates the threshold of acoustic discomfort. Küller commented that despite some inconsistent results, "there remains an impressive amount of significant evidence showing that the illumination and colour of architectural space have a profound influence on the physiology and behavior of man." Whether or not the ambient light affects such objective variables, there is widespread agreement that it does affect subjective reports of perceived comfort, and that blue light is more "restful" than red.[17-22]

A fifth possibility was that there actually was an enhancement of visual sensitivity under blue light. However, a study of detection ranges achieved in the sonar trainer by crews taking refresher courses showed no differences under the various colors of ambient light,[1] and a laboratory study of contrast sensitivity under different ambient colors also produced no differences.[23]

A final reason for the preference for blue was that the blue and red filters were equated for photopic levels of illumination rather than for the mesopic levels at which they were actually used. This results in a much higher brightness for the blue light, owing to the shift in the spectral sensitivity of the human eye toward the short (blue) wavelengths at mesopic and scotopic levels.[24] This fact is seldom taken into account when different colors of light are equated for low light levels. The lights are typically equated using a standard photometer which is designed to operate under much higher light levels.

In short, there were no experimental data to support the idea that blue was preferred to red because it enhanced visual sensitivity; but there was evidence that blue was preferred because the crews chose it themselves, it requires less accommodative power and may produce less visual fatigue, and because sensitivity to blue light is greater than to red.

Several questions remain to be answered. One is whether or not a low-level white light, equated in brightness to the blue light would be as acceptable to the crews as the blue. If it were, the white light would have the advantages of not interfering with the perception of color-coded charts[25] and not interfering as much with dark adaptation as does the blue light.[26] Second, is there a difference in the ability of the sonarmen to detect and classify targets under the different lights? The original evaluations of blue light, which claimed significant improvements in sonar performance, compared

blue light with red. How does performance under blue compare with that under white light? One authority has cautioned that "broadband blue...is, at best, a less than optimal choice. Indeed, the broadband blue lighting may have degrading effects..."[27] He did not speculate what they might be, but he went on to recommend that laboratory studies be carried out. This investigation sought to answer these questions.

EQUATING WHITE, BLUE, AND RED LIGHT

As noted above, it is often the case that when lights of different colors must be equated at mesopic (twilight) or scotopic (nighttime) levels of illumination, the results are faulty. The errors arise from the use of photometers which fail to take into account the changes in the spectral sensitivity of the eye as the light level changes.[28] As the illumination decreases, the eye becomes increasingly sensitive to short (blue) wavelengths and less sensitive to long (red) wavelengths. Thus if the red and blue lights appear to be equally bright at photopic (daylight) intensity levels, the red will appear to be much dimmer than the blue at mesopic or scotopic levels. Most light meters are designed to mimic the brightness sensitivity of the eye at daylight intensity levels. Red and blue lights equated by means of such a light meter will look equally bright at daylight intensities. But when the light level is dimmed, the blue will now be much brighter.

In order to equate the two colors for brightness in the sonar compartments, we must first know the intensity level in the compartments. Surveys of submarine sonar shacks have shown that the light levels measured at rhe sonar dials and work tables average about 0.3 cd/m^2.[29] Knowing the mean level of illumination, we can calculate the discrepancy in the equation of the red and blue illumination made at photopic levels. Kinney[24] has published a nomograph which allows us to make this correction (Fig. 1). The nomograph shows that if the mean photopic luminance, as measured by a lightmeter, is about 0.3 cd/m^2, the effective luminance under blue light is actually 0.55 cd/m^2. To obtain the same effective luminance as that of the blue with white light, we must have a white photopic luminance of 0.5 cd/m^2. (It may be noted, in passing, that to obtain the same effective luminance with red light, its photopic luminance must be even higher, 0.75 cd/m^2. If the red and blue lights are equated photopically at 0.3 cd/m^2, then the effective luminance of the red is only 0.21 cd/m^2, considerably below the 0.55 cd/m^2 of the blue.)

The transmittance of the blue filters which are used to produce the blue light is .032, equivalent to a density of 1.5. To produce the same effective luminance, the transmittance of the neutral filters must be .052, or a density of 1.28.*

* The relationship between transmittance and density is given by the formula

$$\text{Density} = \log_{10} \frac{1}{\text{transmittance}}$$

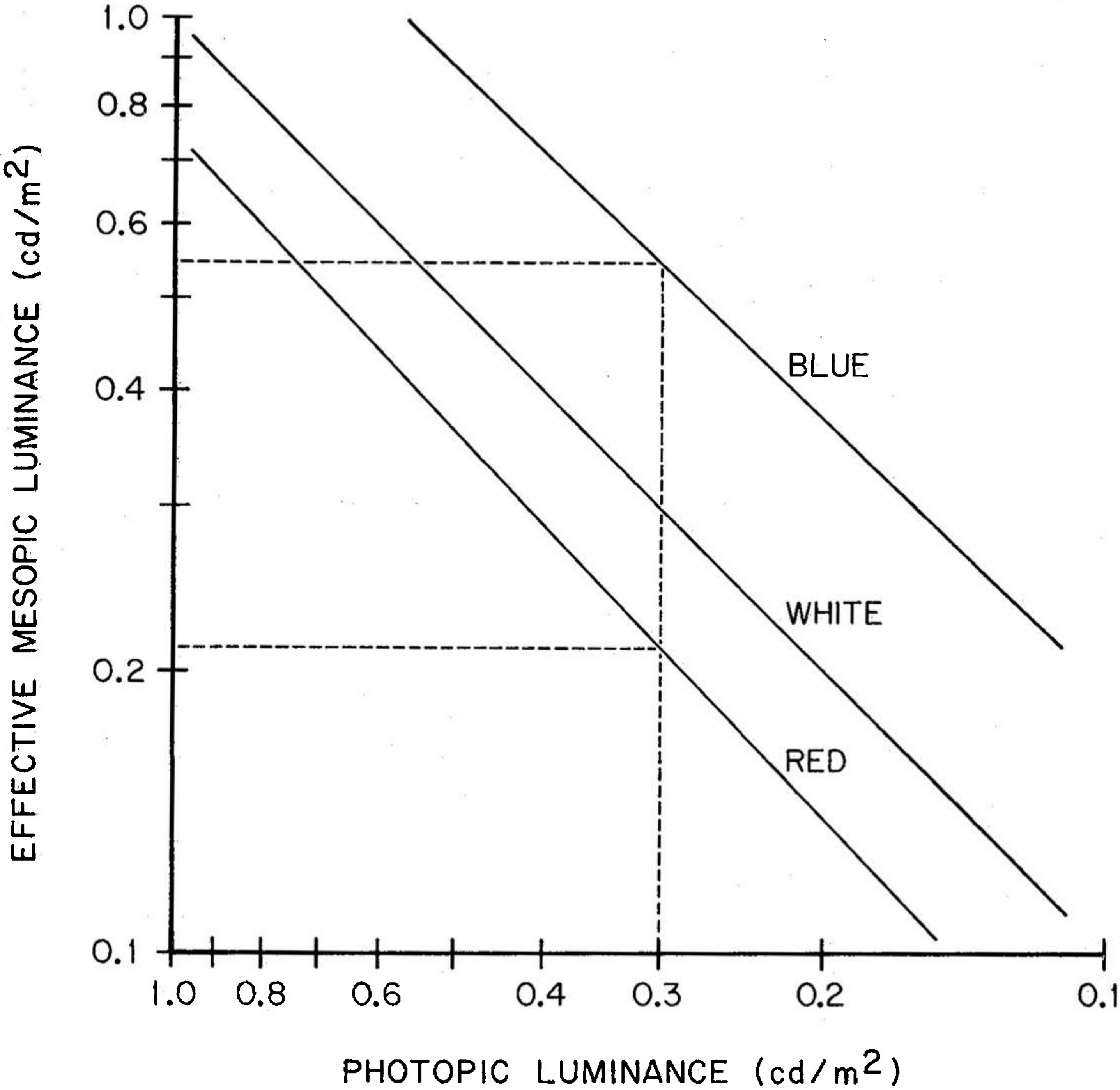

Fig. 1. The effective mesopic luminances of red and blue light filters with daylight fluorescent lamps as a function of photopic luminance (From Kinney[24]).

Since neutral filters are not available in the GSA catalogue, we fabricated some whose density was 1.28 to substitute for the blue filters in use in the Sonar Operations Trainer. In the previous study,[1] the white light was dimmed with black cloth. This makes an excellent neutral density filter, but the men often complained that the room seemed dingy and depressing. We wondered if the sight of the black cloth triggered this reaction, and we therefore used plastic sleeves in this study. The fluorescent tubes and their filters were concealed by the cover of the light fixture; aside from the difference in luminance level, the appearance of the lights was unchanged.

METHOD

Subjective Preferences

To compare the acceptability of the blue and white lighting, 20 sonar crews undergoing refresher training in the Sonar Operational Trainer (SOT) were requested to rate the two ambient colors for various characteristics. Each crew was composed of between 8 and 13 men, with a mean of 9.7.

The SOT contains all the sonar equipment normally carried on a ballistic missile submarine. The equipment is arranged as it is on the 640 class submarine. The SOT provides a realistic simulation of all sonar signals and targets and compares quite favorably with actual conditions at sea. The crews typically spend 2 to 5 eight-hour days in the SOT. Sixteen crews were available for four days. They worked under each light for two days in ABBA or BAAB order. At the end of each day, they answered three questions: Do you think the color of general illumination (1) helps or hinders detection of low signal-to-noise ratio targets? (2) is relaxing or fatiguing? (3) is easy or difficult to work in? They also filled out a "Mood Scale" based on one developed by Johnson and Naitoh[30] at the Naval Health Research Center. It is a self report questionnaire in which the individual rates his feelings of alertness, emotional state, social disposition, and general mood (see Appendix), and it has been widely used in research on fatigue.

The four crews who spent only two or three days in the trainer worked under each of the lights for one day; two crews worked under blue the first day, two under white.

At the end of their last day, whether the second or fourth day, the men answered several additional questions: (1) Which color, blue or white, was easiest to work in? (2) Do you believe either of them made low signal-to-noise targets easier to detect? (3) Do you have any complaints about either of them? (4) Which color would you choose for your sonar room? In addition, they also noted which color was used in the sonar room of their submarine, and they were invited to make any other comments they wished.

Performance Measures

Fifteen crews were subjected to a performance analysis for four days, and performance measures were obtained on three crews for only two days. Each crew followed the watchstanding procedures it would normally follow at sea. The sonar supervisor would report when a contact was detected and when it was classified. No additional requirements were imposed by the experiment.

The performance measure was the time (in seconds) that it took a crew to detect and classify a target. In addition, the times required to detect and classify targets in the baffle area (30 degrees to either side of mid-stern) were recorded separately. The target classifications and ranges were provided by the SOT instructors. Similar targets and ranges were used under both lights. Targets that were not classified correctly were eliminated from the results. The times were therefore divided into eight categories: detection under white or blue light, classification under white or blue light, detection in the baffle area under white or blue light, and classification in the baffle area under white or blue light.

Evaluation at Sea

In addition to the ratings obtained in the SOT, the sonar compartments on five submarines were fitted with neutral density filters, and ratings were obtained from the sonar divisions after a patrol.

RESULTS

Questionnaires

The 20 crews, with an average of about 10 men per crew, returned over 350 responses to each of the questions for each light. The breakdown of these responses is given in Table I. It is obvious that most of the men believed that blue light made it easier to detect low signal-to-noise targets; 73% responded that blue light helped, whereas only 41% responded that white light helped. Only 10% of the men felt that blue light was of no particular benefit or actually hindered detection whereas 39% thought that white light was of no benefit. According to the Chi-square statistic, these differences are highly significant ($\chi^2=95$, df=1, $p<.001$).

Similarly, blue was heavily favored as being more relaxing and less fatiguing to work under than white. This difference is also highly significant ($\chi^2=94$, df=2, $p<.001$).

On the other hand, in response to the question, "Is this color easy to difficult to work in?" there were virtually no differences in the responses ($\chi^2=.68$, df=2, $p<.75$). Thus, although many men pointed out that it was more difficult to read color coded charts under the blue light, this difference was apparently judged to be of relatively less concern.

The results of the mood question-

Table I. Responses (percentages) to Daily questions

Question	BLUE Yes	No	No diff.	WHITE Yes	No	No diff.
1. Does this light help you to detect low signal-to-noise targets?	73	10	17	41	39	20
2. Is this light relaxing to work under rather than fatiguing?	81	12	7	47	40	13
3. Is this light easy to work in rather than difficult?	80	15	5	78	16	6

Table II. Mean positive and negative scores on the Daily Mood Questionnaire for each color

Color	Positive	Negative	P - N
Blue	18.33 ±3.03	4.39 ±2.03	13.94 ±4.76
White	15.49 ±2.80	6.25 ±2.39	9.24 ±4.72

naire also indicated quite clearly the preference of most men for the blue. Each man rated on a 4 point scale how he felt at the end of the day with regard to 24 characteristics, half of them positive (cheerful, efficient, energetic, etc.) and half negative (annoyed, depressed, sluggish, etc.). A total score was obtained which could range from zero to 36 for both the positive and negative group of characteristics.

Table II gives the mean scores for the "positive" and the "negative" characteristics as well as the mean difference between the two scores for each color. Under the blue light, the mean positive score was 18.3 compared to 15.49 under the white. A t-test showed this difference to be highly significant (t=3.08, df=19, p<.01). Similarly, the mean negative score under blue was only 4.4, whereas it was 6.3 under white. This difference is also significant, according to a t-test (t=2.66, df=19, p<.02). The positive-minus-negative differences are significantly greater for the blue light than for the white--13.9 vs 9.2--which is again highly significant (t =3.1, df=19, p<.01).

Table III gives the results of the final questionnaire. Sixty-three percent of the men thought that it was easier to work under blue; only 33% preferred white. Further, 46% thought that it was easier to see the targets on the computer displays under blue light; however, 37% thought there was no difference. Fifteen percent of the men had complaints against blue light, compared to 32% who complained about the white. Finally, when asked which color they would choose for the sonar room, 66% preferred blue compared to 26% for white. Interestingly, 4% preferred red light.

We have also tabulated the preferences within each crew to see how many crews would have voted for each color. Thirteen crews favored blue, six favored white, and the votes for one crew were tied.

Crews' Comments

The men were invited to write down any comments they wished to make about conditions in the sonar room. In analyzing the comments, we have looked for explanations of the heavy preference for blue in spite of the obvious advantages which white light would confer. In fact, the advantages are repeatedly conceded. For example, it is difficult, if not impossible, to read color-coded material under chromatic illumination. Many men also noted that it was difficult to write under the blue light. Blue light would presumably interfere more with dark adaptation than would white. Nevertheless, such factors were not enough to win the men over. The complaints against blue and white were rather similar; those who did not like a given color produced the same reasons for their dislike: the color was depressing or annoying, or produced eyestrain, or reduced alertness.

We therefore tabulated comments which dealt with specific pieces of equipment to see if there were any

Table III. Responses (percentages) to Final Questions

Questions	Blue	White	No Diff.	Red	Black
1. Which color is easiest to work in?	63	33	4		
2. Which color makes it easiest to see targets?	46	16	37	.5	
3. Which color would you choose?	66	26	3	4	1
4. Any complaints about...?	15	32			

Table IV. Mean relative times (sec) taken to detect or classify targets under the blue and white lights. The fastest time is arbitrarily assigned a value of zero and the other times are differences from that time

	White	Blue
Detection	0	11
Classification	169	175
Detection in baffle area	432	769
Classification in baffle area	191	355

patterns. There was no unanimity, but most of the comments indicated that the white light improved and blue light hindered the visibility of the AN/BQR-21 and that of the AN/BQQ-3.

Performance Times

Eight comparisons were made of the times taken to detect or classify targets under the two colors. Table IV gives the times relative to the fastest of the eight times, which is arbitrarily assigned a value of zero. Although mean performance was always faster under the white light, only one blue-white difference was statistically significant. The time taken to detect targets in the baffle area was appreciably faster ($p<.05$) under white light than under blue.

Evaluation at Sea

Five crews evaluated the white light in their sonar control rooms during a patrol. Their results were somewhat different from those obtained in the SOT. Four of the crews preferred the white light to the blue. And the crew which preferred the blue light nevertheless reported that the white light was better for illuminating the BQQ-3. It is noteworthy that two of the crews that expressed a preference for white light over blue at sea had rated the blue more highly after four days in the SOT. One of the crews ranked their preferences for white, blue, red, and "black." This crew preferred white light by a margin of 8 to 1, and they reported a slight preference for red lighting to no lighting at all, presumably because there are tasks carried on in the sonar room that require some light. (Interestingly, this crew requested permission to keep the neutral sleeves and to use the white light in the sonar room permanently.)

Several of the crewman commented that the difference between white and blue light was most apparent during periods of stress; at such times the blue light was felt to add to the tension, whereas the white light reduced the amount of irritability resulting from tracking targets for long durations. This may explain why two crews who favored blue light in the SOT changed their minds after a patrol. Others commented, however, that blue light made the hot sonar compartment seem cooler.

DISCUSSION

In our preliminary study[1] we found that of the three sonar crews, two preferred blue light and one preferred red. There is a similar lack of agreement between the 20 crews who participated in this investigation. This is not surprising. Pressey[31] complained long ago of what he called the "absurd differences of opinion" regarding color preferences. Later investigators, however, were able to show that color preferences are in fact reasonably systematic when both color temperature and luminance are controlled.[32-37] And, indeed, two-thirds of the 200 men again

preferred blue light to white, red, or a darkened compartment. In view of the rather wide agreement that white light was, however, superior to blue for illuminating the AN/BQQ-3 and AN/BQR-21, it is possible that some of the support for white light came from men who were operating those pieces of equipment during the investigation. Several men suggested that although the general compartment lighting should be blue, there should be white light for selected watchstanders, such as the man operating the AN/BQQ-3 and for those men whose duties involved reading the technical manuals and keeping logs, and the like.

Since the blue and white lights had been equated for mesopic luminance, we were surprised by the comments that there was less glare on the AN/BQR-21 under the white light. A possible explanation was that the plastic face of the AN/BQR-21 reflected the two colors differentiately, so that if the operator could see the reflection of the overhead light in the CRT, it was much less noticeable for the white light. To test this, we measured the luminance of the overhead light reflected from the AN/BQR-21, then covered the face of the CRT with white paper, and made another measurement. The ratio of these two provided an index of the amount of glare produced by the blue and white lights. Indeed, the ratio was 6.4 for the white light and 11.8 for the blue light. It was quite clear that the reflection of the blue luminaire was indeed more intense than the white one.

Despite the fact that not all of the men agree on what the lighting color should be, it is clear from the comments that many of them have very strongly held preferences. This is of some importance, because Thayer[38,39] has shown that there is a correlation between reports of how people feel and physiological measures. Liebhart[40] has reviewed the evidence that emotional states are aroused when one believes that one has been exposed to or reacted to an emotional stimulus. Color preferences, therefore, should not be dismissed on the grounds that they appear to be "merely subjective." If, for example, many sonarmen comment that blue light seems cooler, this may to some extent alleviate the temperature problem in sonar rooms reported in the past.

There is disagreement as to whether or not the color of ambient illumination can affect behavior. Most investigators have concluded that it does not, but it must be kept in mind that most investigations have been laboratory studies which have used rather short exposure durations. For example, Greene, Bell and Boyer[22] in their study of the effects of color on boredom, exposed their subjects to the boring task for 10 minutes under each color; Greene and Bell's[21] subjects spent 20 minutes in each treatment condition to see if color affected thermal comfort. Other experimental durations have been 20 minutes,[19] 4 to 29 minutes,[18] half an hour,[6,14] and 60 seconds.[11] It is not surprising that many of these studies do not produce positive results.

Kinney at al,[10] on the other hand, in a study which showed some success

in attempting to induce fatigue, had experimental sessions lasting for one hour, and Fanger, Breum and Jerking[20] exposed their subjects to the experimental conditions for 2.5 hours and found that blue felt slightly, but statistically significantly, cooler than red. And there have been other positive findings.[5,25] The exposures of Kinney et al and Fanger et al are unusually long compared to most experiments, but they do not begin to compare with the long hours which sonarmen spend on duty.

And sonarmen spend this time under extremely saturated hues whether traditional red or the newer blue. Fanger et al[20] criticized the generality of much of the experimental literature on the grounds that in real life "extreme colors would not be acceptable in practice." Although submarines do not constitute a typical human environment, they are all too real. It is no small wonder that Pressey[31] summed up his feelings about the effects of color on performance by saying, "The writer is convinced that there is here a real problem in applied psychology, well worth extended study... But not, let it be repeated, in the laboratory!" The fact that two crews reversed their opinions on the relative merits of white light after an extended patrol shows why Pressey concluded that short laboratory studies cannot provide the answers to such questions.

These results show that there will never be unanimity of opinion on which colors of ambient lights are most desirable. But two conclusions seem warranted. White (neutral density) filters comparable in mesopic brighteness to the blue filters should be made available in the GSA catalogue so that those crews which prefer the white lights should have the opportunity to install them. It is clear that there are difficulties in reading, writing, and dealing with color-coded material under the blue light. And the detection and classification times showed that performance was, if anything, somewhat better under white; although the differences were at times small, they were, nevertheless, consistent. The additional advantages of the white light suggest that it is the most appropriate choice for the sonar compartment. Further testing, however, should be performed on attack and Trident submarines, since their sonar systems use a different color phosphor which may produce different results under these lights.

Second, there seems to be general agreement that even when the blue light is preferred for general ambient illumination, white light is required for the AN/BQQ-3, and white light reflected off the face of the AN/BQR-21 is less distracting than reflected blue light. (It may be noted, hwoever, that installing baffles around the overhead luminaires--a simple matter--would eliminate these reflections.)

CONCLUSIONS AND RECOMMENDATIONS

1. Two-thirds of the nearly 200 sonar operators surveyed preferred blue lighting to white, red, or a dark sonar shack.

2. This preference depends to some extent on the piece of equipment being used. There is more glare on the CRT of the AN/BQR-21 with the blue lighting.

3. Color preferences should be considered in choosing the color of lighting: they are strongly held and may influence operator satisfaction.

4. White (neutral density) light filters should be made available through the GSA catalogue to crews that wish to install them.

5. Baffles should be installed around some of the luminaires to eliminate reflections from the faces of the CRTs.

6. Future research should be done on attack and Trident submarines to evaluate sonar performance on the AN/BQQ-5 and AN/BQQ-6 which have a different phosphor color than the equipment in the present investigation.

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APPENDIX. Mood Scale

INSTRUCTIONS: For each item, choose one of the four answers that best describes how you feel now. Then put an "X" in that box.

Item	Not at all	A little	Quite a bit	Ex-tremely	Item	Not at all	A little	Quite a bit	Ex-tremely
ACTIVE					ENERGETIC				
ALERT					GROUCHY				
ANNOYED					HAPPY				
CHEERFUL					JITTERY				
CAN CONCENTRATE					LAZY				
CONFUSED					RELAXED				
COOPERATIVE					SATISFIED				
DEFIANT					SLUGGISH				
DEPRESSED					SPACED OUT				
DISORGANIZED					CAN THINK CLEARLY				
DULL					TIRED				
EFFICIENT					CAN WORK HARD				

Scores: N P

Scoring: Each response category is assigned a weight: "Not at all", 0; "A little", 1; "Quite a bit", 2, "Extremely", 3. The P score is the sum of the 12 positive items (active, alert, cheerful, can concentrate, cooperative, efficient, energetic, happy, relaxed, satisfied, can think clearly, can work hard). The N score is the sum of the 12 negative items.

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Twenty sonar crews (mean=9.7 men) undergoing refresher training in the Sonar Operational Trainers (SOT) for two to five 8-hour days evaluated the acceptability and effectiveness of blue and white ambient lighting. In addition, five crews evaluated the white lighting at sea. Of the nearly 200 men tested in the SOT, two-thirds preferred blue to white lighting, although there was general agreement that such pieces of equipment as the AN/BQQ-3 and AN/BQR-21 should be white lighted. Of the five crews tested at sea, four

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20, continued:

preferred white and only one preferred blue. Two of the crews that preferred white had originally preferred the blue lighting when tested in the SOT. Possible reasons for this change are discussed.